MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 3, 2017/2018

ENT3076 – NANOSCIENCE
(NANO)

4 JUNE 2018
9:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTION TO STUDENT

1. This Question paper consists of **6** pages including cover page with **FOUR** Questions only.

2. Attempt all **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided. Remove **Page 6** from Question Booklet and submit together with Answer Booklet.

Question 1

(a) Draw the graph of density of states for electrons in quantum well, quantum wire and quantum dot. Label the energy levels clearly at the energy axis. Assume the dimensions at the confinement directions are equal. [6 marks]

(b) A quantum well with 20nm-thick active material is fabricated using gallium arsenide (GaAs) and aluminium nitride (AlN). **Table Q1(a)** lists the information of these two materials.

Table Q1(a)

Material	Electron Affinity	Eenergy Bandgap	Electron Effective Mass	Holes Effective Mass
GaAs	4.07eV	1.42eV	$0.063m_o$	$0.51m_o$
AlN	0.60eV	6.2eV	$0.4\ m_o$	$3.53m_o$

(i) Determine the quantized energy, ε_i of the holes at energy levels 1, 2 and 3, respectively. [6 marks]

(ii) Calculate the density of states per unit area for holes if the total energy of holes gas in the quantum well is 10meV. [4 marks]

(c) Two-fold degenerate of an energy-level in double heterostructure can be represented by the formula:

$$\varepsilon_i^{\pm} = \varepsilon_i + s_i \pm t_i$$

(i) Briefly explain the process attributed to s_i and t_i on the initial energy state. [2 marks]

(ii) Sketch the diagram of energy levels and wave functions for a double-well heterostucture. Label the initial energy state (ε_i), shifted energy states (ε_i^+, ε_i^-) and indicate symmetric and antisymmetric wave functions in the diagram. [7 marks]

Question 2

(a) Draw and highlight the first Brillouin zone in **Figure Q2(a)** on **Page 6**. [6 marks]

(b) With the aid of diagrams, briefly explain the formation of light holes and heavy holes in the valence band. [10 marks]

Continued ...

(c) Carriers are scattered by the electric field of an ionized impurity in a semiconductor. For an N-type semiconductor, the scattering potential is the screened Coulomb potential of:

$$U_S(r) = \frac{q^2}{4\pi\kappa_S\varepsilon_o r} e^{-\frac{r}{L_D}}$$

(i) Derive the equation of unscreened Coulomb potential from the equation above which is used in semiconductor with low mobile carrier density. The meaning of each symbol is given in the list of constants. [4 marks]

(ii) If a positive charge is located at a distance of 400nm from the ionized impurities in an n-type silicon with concentration of $1\times10^{9}\text{cm}^{-3}$, calculate the Coulomb potential. [5 marks]

Question 3

(a) (i) Differentiate between cold, warm, and hot electrons. [3 marks]

(ii) With the aid of diagrams, discuss the spherically symmetric and streaminglike electron distributions. [10 marks]

(b) **Figure Q3(a)** shows the drift velocity of electron in GaAs at different electric fields. What is this effect? With the aid of a diagram, briefly explain the reason of this effect. [6 marks]

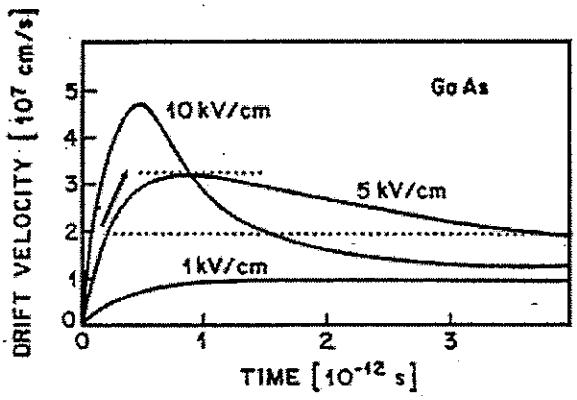

Figure Q3(a)

(c) Given the first quasi-bound state energy (ε_1) is 35meV, the barrier width (L_w) is 10nm, the electron effective mass (m^*) is $0.039m_o$, and assume that the electron energy (E) exactly coincides with ε_1, calculate:

(i) the transverse velocity of electron (υ_s) in the well; [2 marks]

(ii) the probability of tunneling through the barrier (Γ); [2 marks]

(iii) the lifetime of electron (τ) in the well. [2 marks]

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Question 4

(a) (i) Name the device which is shown in **Figure Q4(a)** and name the terminals which are labelled by **E**, **F** and **G**, respectively. [2 marks]

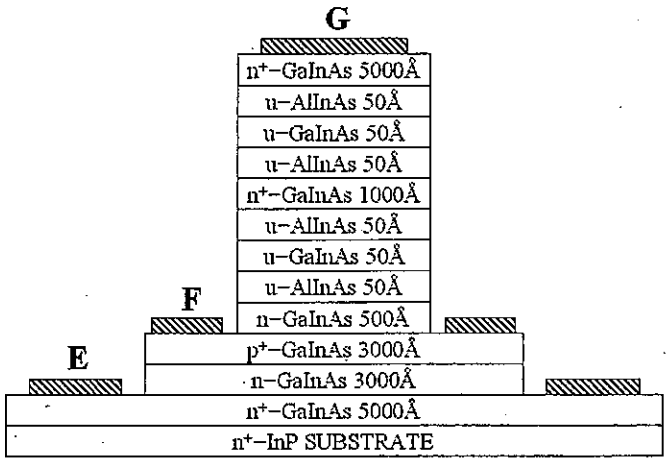

Figure Q4(a)

(ii) By using diagrams, explain the operation of the device shown in **Figure Q4(a)**. [6 marks]

(b) According to selection rules for electron transition, determine the first **THREE** wavelengths that can be emitted by the light emitting diode that is described in **Question 1(b)**. [12 marks]

(c) Define intraband phototransistion. Explain why intraband phototransition is impossible in a bulk GaAs but possible in a AlGaAs/GaAs heterostructure. [5 marks]

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List of constants

Electron mass in free space, $m_o = 9.11\times 10^{-31}$ kg
One electron volt, (1eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Electronic charge, $q = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.06 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}
Relative permittivity of silicon, $\varepsilon_r = 11.7$

List of Formulas

$$n = 1 + \sqrt{\frac{2m^* V_b L^2}{\pi^2 \hbar^2}}$$

$$\varepsilon_{n1,n2} = \frac{\hbar^2 \pi^2}{2m^*}\left(\frac{n_1^2}{L_x^2} + \frac{n_2^2}{L_y^2}\right)$$

$$\varepsilon_1 \approx \frac{m^* V_b^2 L^2}{2\hbar^2}$$

$$\frac{\rho}{L} = \frac{1}{\pi}\sqrt{\frac{2m^*}{\hbar^2}} \sum_{n1,n2} \frac{1}{\sqrt{E - \varepsilon_{n1,n2}}} \Theta\left(E - \varepsilon_{n1,n2}\right)$$

$$\frac{\rho}{S} = \frac{m^*}{\pi\hbar^2} \sum \Theta\left(E - \varepsilon_n\right)$$

$$N_t = \frac{2\sqrt{2}m^{*\frac{3}{2}}}{3\pi^2\hbar^3}\left|V_b\right|^{\frac{3}{2}} L_x L_y L_z$$

$$L_D = \sqrt{\frac{\kappa_o \varepsilon_o k_B T}{q^2 n_o}}$$

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Question 2(a)

Submit this page with the answer booklet.

[6 marks]

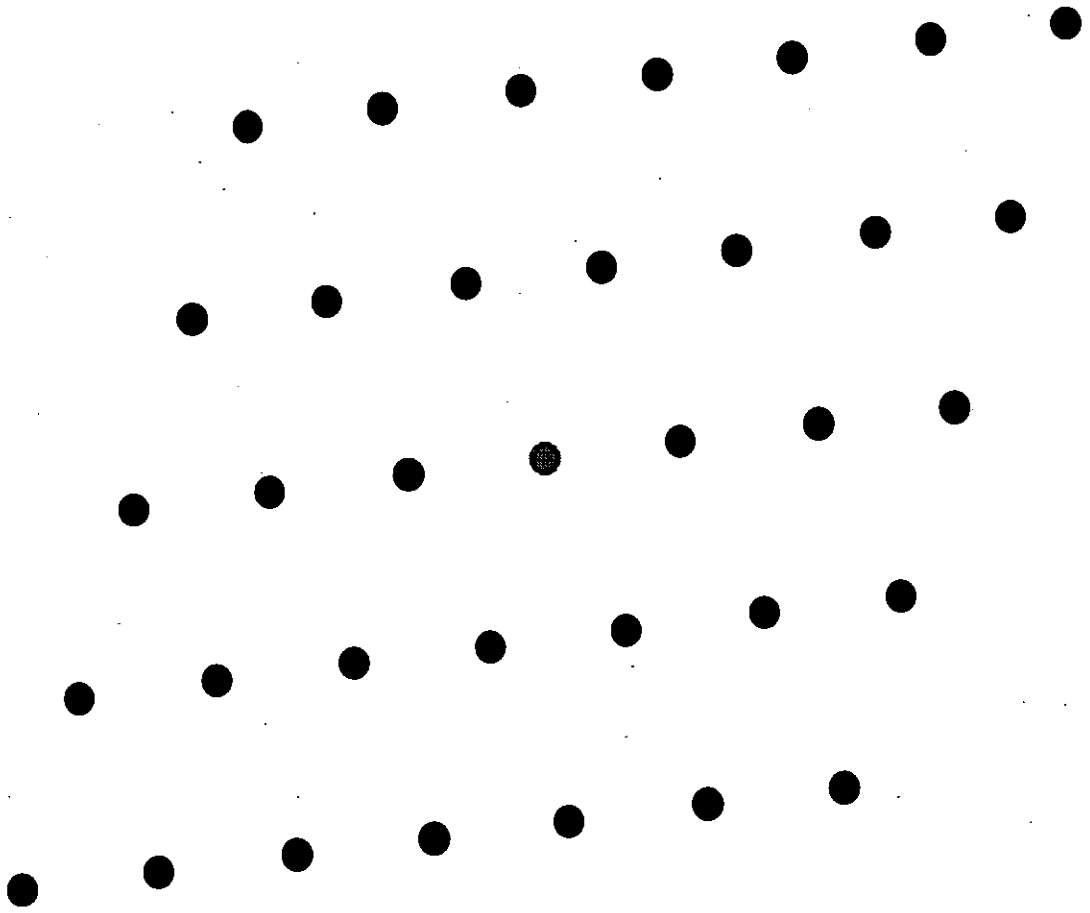

Figure Q2(a)

End of paper.